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NEUTRINO PROTON SCATTERING AND THE ISOSINGLET TERM

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ABSTRACT

Elastic neutrino proton scattering is sensitive to the SU(3) axial isosinglet term which is in turn dependent on the strangeness content of the proton. The uncertainties in the analysis of a neutrino proton elastic scattering experiment are discussed, and an experiment which is insensitive to many of the difficulties of the previous experiment is described.

1. Introduction

The cross section for semi leptonic exclusive channels is conventionally written in the form

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2 M^2 \cos^2\theta}{8\pi E_\nu^2} [A(Q^2) \pm B(Q^2) W + C(Q^2) W^2] \qquad (1)$$

$$A = \tau [4(1+\tau) |g_A|^2 - 4(1-\tau) |f_1|^2 + 4\tau (1-\tau) |f_2|^2 + 16\tau f_1 f_2$$

$$B = -16\tau \; g_A (f_1 + f_2)$$

$$C = 4(|g_A|^2 + |f_1|^2 + \tau |f_2|^2)$$

with

$$\tau = Q^2 / 4 m_p^2 \qquad\qquad W = 2 m_p E_\nu - Q^2$$

The difference between particular channels is expressed by coupling constants related to the appropriate hadronic charge. The vector charged couplings are proportional to the electrical charge of the hadron and the anomalous magnetic moment. There is also a SU(3) symmetric vector coupling which does not appear in electron scattering because in the approximation that only u, d and s quarks are involved, the sum of the charges is zero and hence no term appears in photon mediated processes. Axial current terms appear in parity violating electron scattering as well as in neutrino induced processes. In table I is listed the appropriate charges on the proton for charged and neutral current scattering.

Table I	Vector	Axial Vector
Isotriplet	$1 - 2\sin^2\theta_W$	-1
Isosinglet SU(3) octet	$1/\sqrt{3}\,(1 - 2\sin^2\theta_W)$	$-1/\sqrt{3}$
Isosinglet SU(3) singlet	$-1/2$	$1/2$

Neutrino proton elastic scattering is an example of a neutral current process involving hadrons. Analysis of these data at finite Q^2 depend on form factors describing both vector and axial vector hadronic currents. The vector form factors (parameterized by M_V in a dipole fit) are taken from electron scattering assuming CVC (the conserved vector current hypothesis). The axial current parameters are $G_A(0)$, M_A. G_A is most precisely derived from neutron decay, and M_A from quasi elastic scattering as will be discussed below. Using the weak charges in table I it follows that the axial coupling to the proton is

$$G_{NW} = -G^0{}_3/2 - G^8{}_1/\sqrt{3} + G^0{}_1/2$$

$G^0{}_3$ is 1.26 from neutron decay, and $G^8{}_1$ is 0.162 ± 0.008 from hyperon decay.

2. Data and Fit

The beam of neutrinos that was used originated from the Brookhaven AGS, and has been described in Ref. 1. Both neutrinos and antineutrinos are available with energies that peak a little above 1 GeV. The contamination of wrong sign helicities in each beam is small and is discussed below. The beams are dominated by muon neutrinos with a contamination of electron neutrinos that was typically 1%. These beams have been understood both by measuring quasi elastic scattering and by extensive simulation. Uncertainties in the beam flux contribute a small systematic error.

The detector was a fully active detector[2] consisting mainly of liquid scintillator cells as a target medium and total absorption calorimeter. Particle directions were determined using a proportional drift system interleaved between the liquid scintillator cells. In addition the deposited energy in each cell was recorded allowing particles to be identified by dE/dx. At the rear of the detector was a charged particle spectrometer designed to measure the muon momenta from the quasi elastic reactions

$$\nu_\mu + n \rightarrow \mu^- + p \qquad (2)$$

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n \qquad (3)$$

These reactions were identified by excluding other activity in the detector (from inelastic channels for example); these cuts were such as to include almost all of the scattering events from nucleons bound in nuclei.

The signature for neutrino proton elastic scattering at intermediate energies is rather modest. In the case of this detector, a charged particle track was identified as a proton from the deposited energies in the cells along the track. The direction of the track was reconstructed from the drift tube hits, and the vertex location from the low energy deposition at the start of the track. Events in which there were other hits in detector elements in time coincidence with the identified track were removed. This served to remove inelastic events from pion production for example. Background in single track events from particles other than protons was very low. However, recoils from neutron scattering events could potentially be a problem. These neutron induced events were removed by two cuts, the first that the events should be in time with the beam spill removed most of the late events from low energy neutrons, and a fiducial volume selected in the center of the detector removed the remaining early arriving neutron events. It was verified that the event sample was almost completely neutrino induced by plotting the arrival time of the events. The events showed the time structure induced by the RF modulation of the proton beam in the accelerator; this time structure is lost by neutron induced events.

The restriction to one track without other time coincident activity together with particle identification served to provide a clean sample of events. A Monte Carlo simulation was used to estimate the background and make corrections to the cross section.

The neutrino flux was determined from quasi-elastic events of reactions 2 and 3 with a cut that the outgoing muon have an angle less than 20° to the neutrino direction. Cross sections for reactions 2 and 3 are well known at low Q^2, and the principal uncertainty in deriving the neutrino flux comes from residual background in event selection. The normalization is made from events in the same data samples.

The cross-section data is plotted in Fig. 1. for both neutrinos and antineutrinos[3]. The results of a fit to the data are also shown in the figure. Parameters that enter into the cross section fits are $\sin^2\theta_W$, M_A, and η, $\sin^2\theta_W$ was set at 0.220 guided by the results of

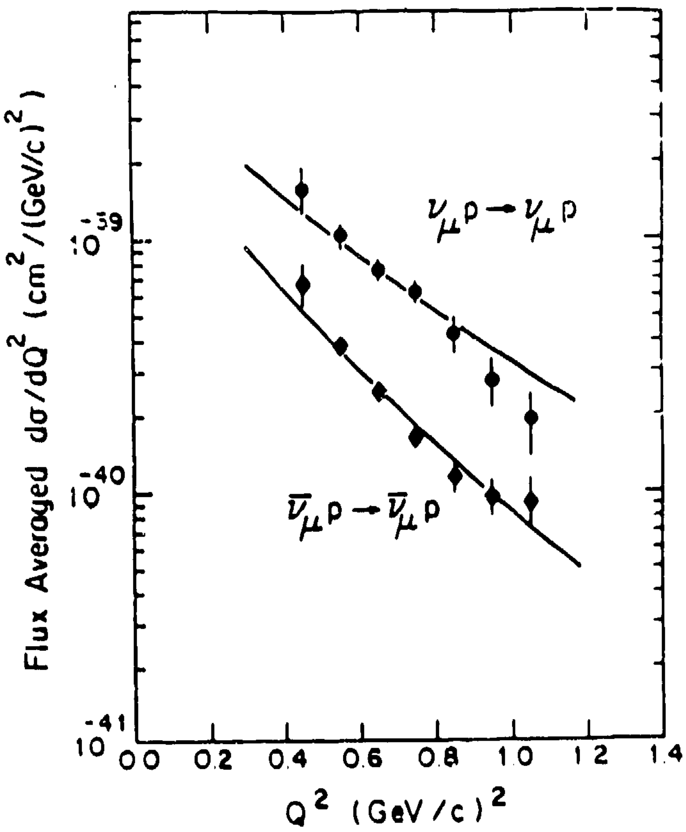

Figure 1

a global fit to all the available data on $\sin^2\theta_W$, other parameters are sufficiently well known so that accepted values for each were used (e.g. M_V, $G_A(0)$). A fit was also made allowing M_A and η to vary simultaneously, contours of χ^2 corresponding to this fit in M_A, η space are shown in Fig. 2. It is seen that M_A and η are strongly correlated which introduces an extra complication into the interpretation of these data. The three terms in the expression of the cross section (1 above) all are dominated by G_A, A and C by $G_A{}^2$ and B by G_A. Since the fit is dominated by the value of the cross section at $Q^2 \sim 0.6$ GeV/c^2 this cross section depends on the value of $G_A(0)$ and the slope against Q^2 given by M_A. We shall discuss here the results from a fit to extract η with M_A set at 1.03 GeV/c^2, the world average value. The fit value for η is then 0.12 ± 0.07. This is nearly a two standard deviation effect, which can be regarded as indicative of a possible strange contribution but hardly a substantial measurement.

Subsequent to this analysis a concern was pointed out to us by Gerry Brown[4]. He pointed out that M_A would be modified by medium effects in the nucleus, in this case ^{12}C. The value of $G_A(o)$ is also likely to be renormalized by a few percent. The effects are likely to be small, approximately 5%, but as can be seen from Fig. 2 this affects the value of η considerably (0.15). An explicit measurement of M_A was made in this experiment by using antineutrino quasi-elastic scattering giving $M_A = 1.09 \pm 0.04$, however, this analysis used the value of $G_A(o)$ from neutron decay and M_V from electron scattering on free nucleons. It is not clear short of a complete reanalysis how medium effects would modify the value of M_A given these complications, and since one third of the nucleons are free in the Brookhaven detector. The choice of the world average for M_A of 1.03 GeV/c^2 was probably wise for analysis of ν_μ p elastic scattering. Some questions remain, and a reanalysis is called for because of the sensitivity of η to the value of M_A and even $G_A(o)$.

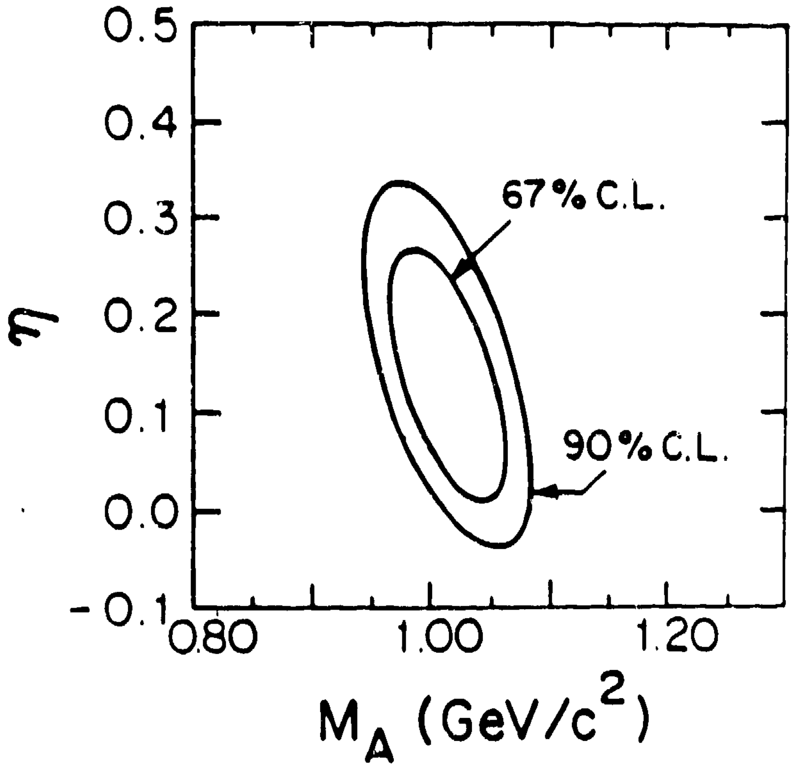

Figure 2

A method has been proposed at LAMPF[5] to avoid this dependence on M_A in the measurement of G_A. At low $Q^2 < 0.1$ GeV/c^2 the effect of M_A is minimized so that the cross section measurement is related directly to the value of the form factor at zero Q^2. Moreover, the values of A and C in the expression (1) depend on $|G_A|^2 + |F_1|^2 + Q^2/4 m_p^2 |F_2|^2$, so that at low Q^2 the third term is negligible. $F_1 = (1 - 4\sin^2\theta_W)$ and is very small so that the cross section at low Q^2 is almost directly the quantity of interest, namely the effective G_A. In Fig. 3 is shown a schematic of the detector, a 200-ton tank of liquid scintillator viewed by a a large number of phototubes to detect the recoil proton in the energy range 20 to 40 MeV. The cross section is shown in Fig. 4 for a few values of the incident neutrino energy as a function of Q^2. The cross section will then be measured as a function of Q^2 integrated over the incident neutrino spectrum, which is not only well known but not very important for the cross section determination at zero Q^2. A measurement of G_A to a few percent is anticipated.

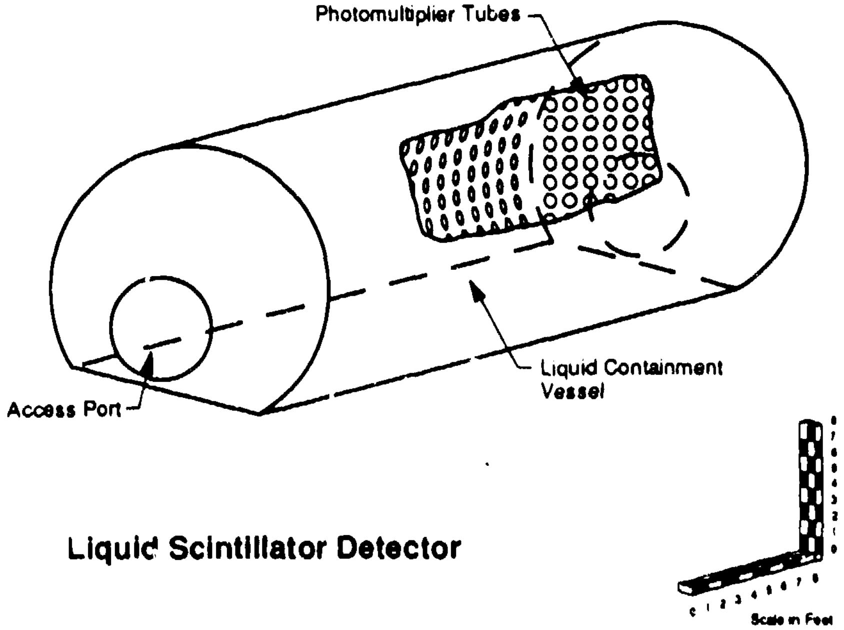

Figure 3

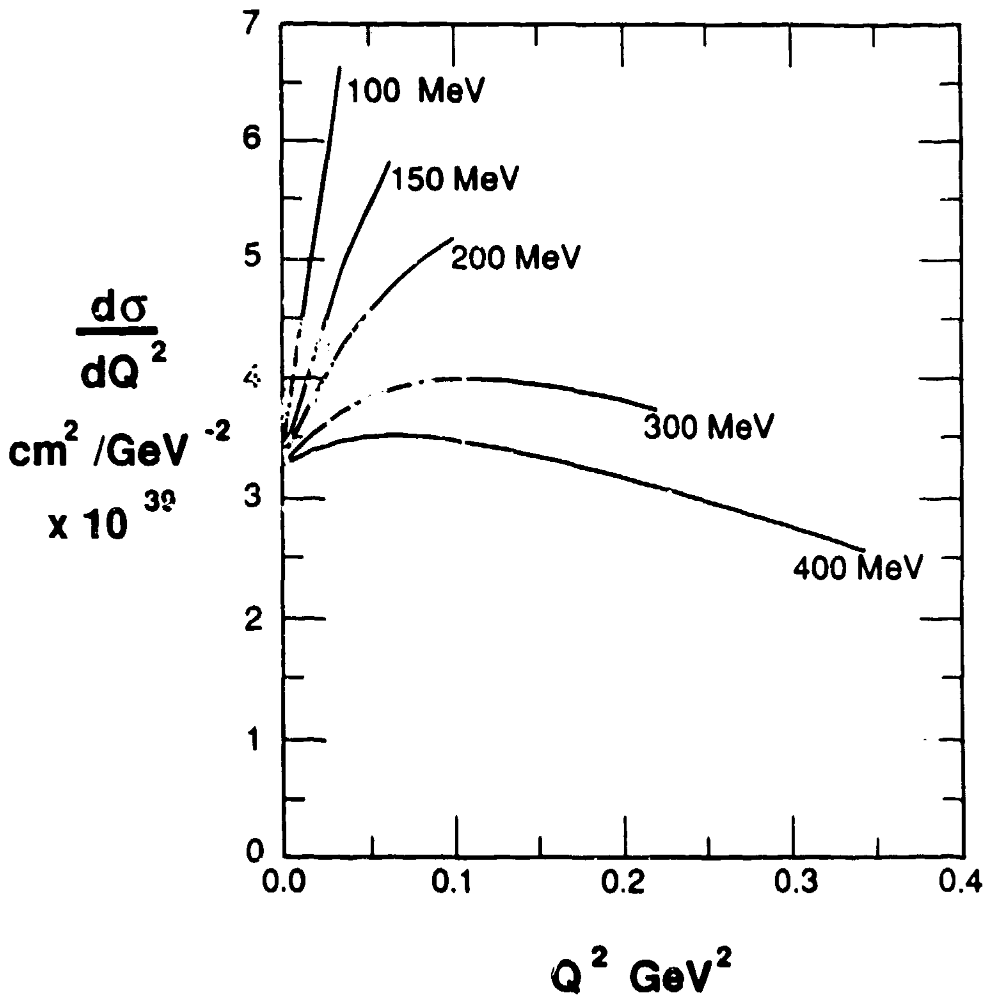

Figure 4

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